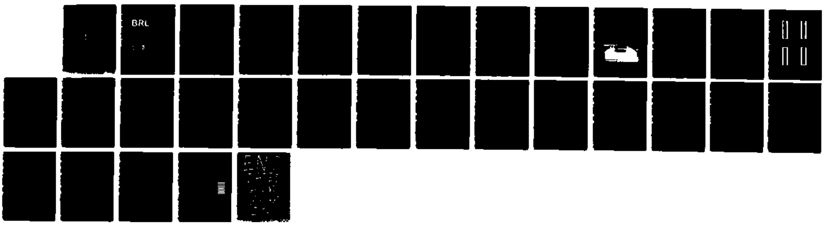
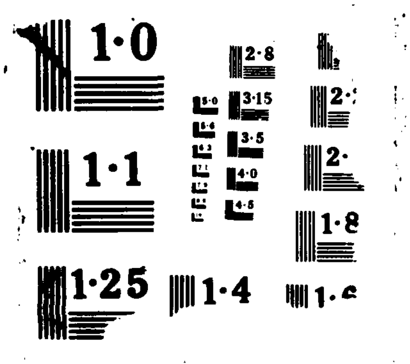
AD-A195 881 FLAMESPREADING PROCESSES IN OBLIQUELY LOADED STICK PROPELLANT BEDS(U) ARMY BALLISTIC RESEARCH LAB ABERDEEN PROVING GROUND MD T C MINOR MAR 88 BRL-TR-2894 1/1

UNCLASSIFIED F/G 19/1 NL




1·0
2·8
3·15
3·5
4·0
4·5
1·1
1·8
1·25
1·4

UIIC FILE COPY

BRL-TR-2894

(4)

AD-A195 081

TECHNICAL REPORT BRL-TR-2894

BRL

1938 – Serving the Army for Fifty Years – 1988

FLAMESPREADING PROCESSES IN OBLIQUELY LOADED STICK PROPELLANT BEDS

THOMAS C. MINOR

MARCH 1988

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

DESTRUCTION NOTICE

Destroy this report when it is no longer needed. DO NOT return it to the originator.

Additional copies of this report may be obtained from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.

The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The use of trade names or manufacturers' names in this report does not constitute indorsement of any commercial product.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

A175 ...

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) BRL-TR-2894	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Ballistic Research Laboratory 6b. OFFICE SYMBOL (If applicable) SLCBR-IB-A	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Aberdeen Proving Ground, MD 21005-5066	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: 61102A PROJECT NO.: 1L161102AH43 TASK NO.: 00 WORK UNIT ACCESSION NO: 00

11. TITLE (Include Security Classification)

Flamespreading Processes in Obliquely Loaded Stick Propellant Beds

12. PERSONAL AUTHOR(S)

Thomas C. Minor

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical Report	FROM Oct 85 TO Sep 86		

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
19	01	
19	10	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Interior Ballistics, Artillery Propelling Charges, Stick Propellants, Flamespreading, Guns, Gun Propellants, Flow Resistance

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Stick propellants have seen increasing use in recent years, in part because the small resistance to the flow of ignition and early combustion gases presented by the packed stick bundle allows the use of simplified, base ignition systems. The resistance to gas flow along the axial dimension is approximately two orders of magnitude lower for a stick propellant bed than for a granular one. However, in the real world of propellant charges, conditions arise in which the flow of gases might attack the stick bundle obliquely rather than along its axis. Such situations might include propellants contained in cases in a manner that the sticks can become shifted or twisted to some degree of obliquity either during the loading process or during handling prior to firing. A similar situation might arise with a central primer venting into a stick bed, in which case the flow might be perpendicular to the axis of the sticks. Clearly, to varying degrees the picture of nearly resistanceless flow within the bed does not apply in these cases.

(continued on reverse side)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Thomas C. Minor	22b. TELEPHONE (Include Area Code) (301) 278-6176	22c. OFFICE SYMBOL SLCBR-IB-A

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

This paper reports a study carried out in a simulator for the 155-mm howitzer in which special stick propellant charges were examined during the flamespreading portion of the interior ballistic cycle. The charges were constructed such that varying amounts of radial twist of the propellant sticks along the length of the bundle were given to the charges during assembly. Examined during this early period were the path of flamespreading, pressurization at both ends of the chamber, movement of the propellant bundle, and solid-phase loading on the base of the projectile.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

For some time now, stick propellants have been an option in favor with charge designers. With the emergence of a domestic stick propellant manufacturing capability, stick propellants are seeing increased application to US charges, either in those already type classified, such as the 155-mm, M203A1,[1] or charges in varying degrees of development, such as the 155-mm, XM216 modular charge[2] or the 155-mm "universal-increment" charge.[3] Stick propellants enjoy their popularity, in part, due to the ease with which gases flow through the natural flow channels presented by the stick propellant bundle. This geometry allows use of simplified and reliable base ignition systems rather than some other means, such as a centercore, to distribute the ignition stimulus uniformly throughout the charge, thus mitigating localized ignition and the deleterious axial pressure waves that can be caused by localized ignition.

Several previous studies have been conducted on flamespreading in stick propellants.[4-6] In a direct comparison of full-bore, one-dimensional granular and stick propellant charges in a simulator for the 155-mm howitzer,[4] significant differences were seen in the flamespread through the two charges. While the orderly, axial progress of a flamefront could easily be discerned with a granular charge, there was no well-defined flamefront through the stick charge. Rather, flame first appeared at the rear of the charge, then luminosity appeared in the axial ullage forward of the charge, and later the entire charge began to increase in luminosity uniformly, without any obvious convectively driven ignition wave through the charge. As part of a series of

---

[1]David L. Kruczynski, "Final Report: Product Improvement Test of 155-mm Propelling Charge M203E2," Combat Systems Test Activity, USA TECOM, Aberdeen Proving Ground, MD, January 1986.

[2]Sandor Einstein, Scott Westley, and Robert Garufi, "Development of a Single-Base Stick, 155-mm, Modular Charge," Proceedings of 1986 JANNAF Propulsion Meeting, CPIA Publication 455, Vol. IV, pp. 131-136, August 1986.

[3]Aaron Grabowsky, Philip Hui, and Donald Chiu, "Unicharge for Integrated Smart Artillery Synthesis," Proceedings of 1985 JANNAF Propulsion Meeting, CPIA Publication 425, Vol. III, pp. 453-465, April 1985.

[4]Thomas C. Minor, "Experimental Studies of Multidimensional, Two-Phase Flow Processes in Interior Ballistics," ARBRL-MR-03248, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, April 1983.

[5]Thomas C. Minor and Albert W. Horst, "Ignition Phenomena in Developmental, Combustible-Cased, 155-mm, M203E2 Propelling Charges," ARBRL-TR-02568, Ballistic Research Laboratory, USA AMCCOM, Aberdeen Proving Ground, MD, July 1984.

[6]Thomas C. Minor and Albert W. Horst, "Theoretical and Experimental Investigation of Flamespreading Processes in Combustible-Cased, Stick Propellant Charges," BRL-TR-2710, Ballistic Research Laboratory, USA LABCOM, Aberdeen Proving Ground, MD, February 1986.

flamespreading tests conducted with combustible-cased stick propellants,[6] again in the 155-mm howitzer simulator, the importance of the jump conditions at the entry plane of a stick propellant bundle was noted. While gases enjoy a nearly resistanceless flow within a stick bundle, the discontinuity in porosity associated with the bundle entrance made it difficult for gases to enter the bundle, so much so that the igniter gases took an alternate, unexpected path into the charge.

Several points served as motivation for this particular study in which the effects on the flamespreading process of non-axial alignment of the sticks with the principal axis of flow were examined. It has been our observation that even though the intent may be to load the propellants in a well-constrained bundle in which all the sticks are aligned with the axis of the charge, such a configuration does not always obtain at the time of firing of the charge. Sticks can become twisted in the charge so that they are no longer axially aligned. Indeed, such observations have been made with versions of the M203A1 or the XM216 in disassembling the charges or examining them with flash radiography.

Situations may arise in which a centrally venting primer is required even in a stick charge. As an possible example, consider programmed-splitting stick propellant,[7] in which an array of slits is embedded in a stick grain to be uncovered at some later portion of the interior ballistic cycle, exposing more surface area and increasing the amount of evolving gases to work on the projectile. This concept relies on a seal of the end of the stick to ensure that the slits are not opened prematurely, resulting in potentially catastrophic overpressures. Recent testing has indicated that perhaps a direct venting of a harsh base igniter on the stick ends promotes early failure of the end seal, so that a softer base igniter or perhaps even a centrally venting igniter may be called for.

These above scenarios present situations in which the flow is not along the principal axis of the stick propellant bed. While the resistance to flow through a bundle in which the sticks are axially aligned is significantly less than that for a randomly loaded granular charge, it would appear conceptually that the flow at oblique angles of attack can progress from something greater than that now seen with axially aligned sticks to infinite impedance with completely transverse flow. This study examined some of the issues addressed above, and provided a first step, to be coupled with other fixture tests and gun tests, to assess the ballistic significance of obliquely loaded or twisted stick propellant bundles. Somewhere in the progression of these experimental studies, the need for new flow correlations for multiphase flow interior ballistic models to adequately treat this situation will have to be addressed, so as to aid in updating these models which strive to be phenomenologically complete.

---

[7] F.W. Robbins and A.W. Horst, "High-Progressivity/Density (HPD) Propelling Charge Concepts: Progress of Programmed-Splitting Stick Propellant," BRL-MR-3547, Ballistic Research Laboratory, USA LABCOM, Aberdeen Proving Ground, MD, September 1986.

II. EXPERIMENTAL

A. Apparatus

Figure 1 depicts the apparatus used at the Ballistic Research Laboratory to conduct the experimental investigation. The illustration of the simulator for the 155-mm howitzer shows the mount with a clear plastic simulator for the 155-mm chamber in place. Although the mount also accepts higher-pressure, filament-wound fiberglass chambers, the plastic chambers were used in this study to a permit better view of the events transpiring within. The cast acrylic chambers used in this study had a nominal interior diameter of 165 mm and a nominal outer diameter of 191 mm. The muzzle end of the chamber was closed by a modified M101 Projectile seated in a section of gun tube machined to the dimensions of the M199 Cannon. The breech end of the chamber was closed by a spindle similar to the mushroom configuration of the M185 Cannon with the primer spithole located in the center of the spindle, housing three piezoelectric pressure transducers. Only two of the pressure gages in the spindle were used for this study. An instrumented baseplate, shown in Figure 2, was attached to the base of the projectile; it permits two gas pressure, three total force, and two acceleration measurements at the projectile base. For this study, only two pressure and two force measurements were taken.

Photographic data were recorded with two high-speed, 16-mm cameras. Both cameras were mounted with lenses to record the overall aspects of the event. With both the cameras, data were recorded at a framing rate of approximately 5000 pictures per second. One-kHz timing signals were placed on the films by electronic circuits internal to the cameras, and the firing fiducial (time at which the firing voltage is applied to the gun) was also placed on the films to aid in correlation of the film data with other data.

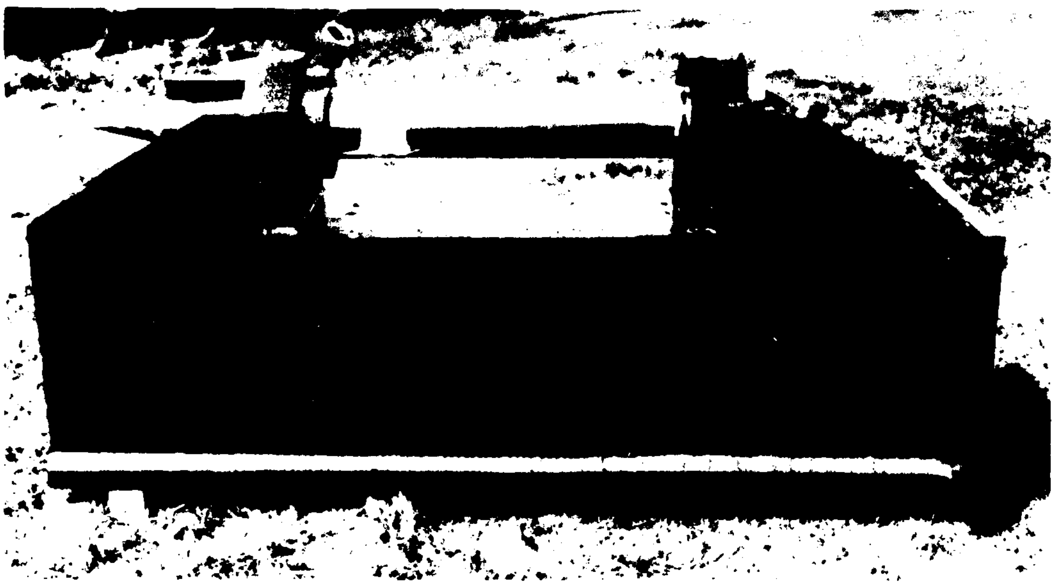


Figure 1. 155-mm Howitzer Simulator

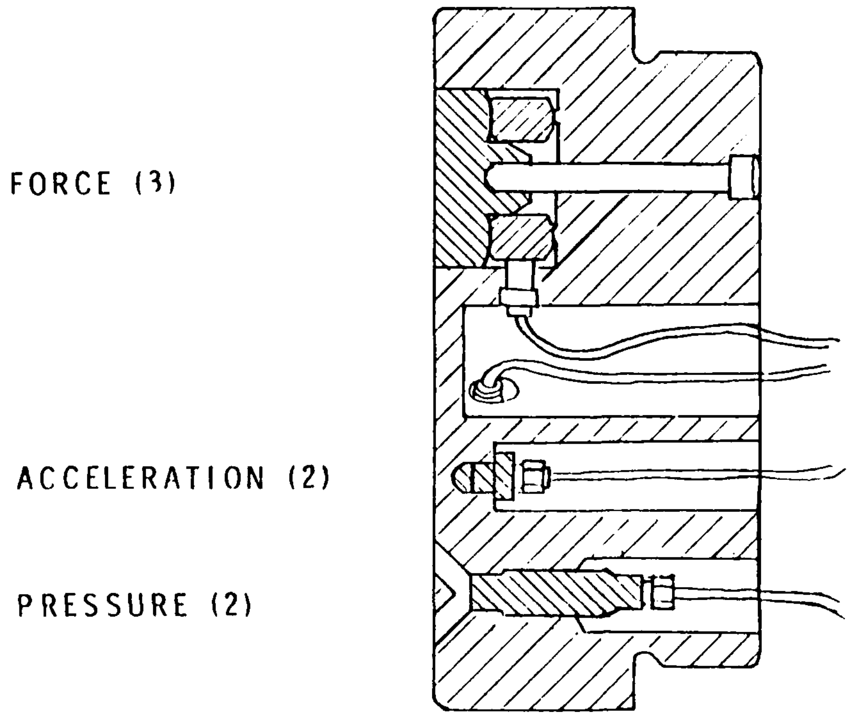


Figure 2. Instrumented Projectile Baseplate

Flash radiography was used to monitor the behavior of the solid phase during the interior ballistic cycle. A single 1-MeV head was employed, aligned perpendicular to the chamber axis and providing a sufficient fan of radiation so as to completely cover the length of the chamber. One image (a "static" shot) was taken of the charge in the chamber before firing, and a second, on a separate film, was recorded during the event by X-rays triggered at a predetermined spindle pressure (a "dynamic" shot). The X-ray film was protected from the blast of the disposable chamber by a wooden cassette, with the forward face composed of layers of sacrificial wooden plates separated by air spaces.

B. <u>Charge Design</u>

The charges used in this study were constructed with M30A1 slotted single-perforation propellant from lot RAD-PE-738-1C. This propellant has a length of 736 mm, an outer diameter of 6.37 mm, and a perforation diameter of 2.16 mm. In order to assess the effects of the nonaxial alignment of the sticks in the bundle on the flamespreading process, the charges were made to full chamber diameter so that circumferential ullage would not provide a path of least resistance to gas flow. The design of the chamber employed by the simulator rendered it impossible to have a constant angle of obliquity for attack of the initial igniter and combustion gases, so as an approximation, the propellant sticks were twisted about the longitudinal axis of the bundle so as to offer a nonzero angle of attack of the gases. The charges were constructed in layers, beginning by giving the inner layer the desired amount of twist, and then overlaying successive layers aligned with the inner until full chamber diameter was achieved. An initial loading study determined that with the maximum twist possible, the angular displacement of the outer layer of propellant, from end to end, was approximately 66°. For this study, charges were fabricated with this maximum twist, with two-thirds of the maximum twist, one-third of the maximum twist, and with no twist. Table 1 lists relevant data for these charges.

Figures 3, 4, 5 and 6 illustrate the four charges fired in this study prior to assembly with an igniter. The figures show, respectively, the propellant sticks bundled axially aligned, with a one-third maximum twist, with a two-thirds maximum twist, and with a maximum twist. As a visual aid, an individual stick on each of the twisted charges is marked to highlight the twist of the sticks along the charge length.

Basepads were prepared by altering standard 8-inch, M2 basepads. A circular pouch, 38 mm in diameter, was sewn in the center. Fourteen grams of Class 5 black powder were inserted into this pouch and the balance of the basepad was filled with 56 g of Clean Burning Igniter (CBI). The finished basepads were taped to the end of the stick bundles and nearly covered the entire diameter of the propellant bed.

Table 1. Characteristics of Experimental Charges

Charge No.	Mass (kg)	Twist of Outer Sticks	Relative Twist
1	16.48	0^{o}	straight
2	16.34	26^{o}	1/3 maximum
3	16.52	48^{o}	2/3 maximum
4	16.46	66^{o}	maximum

III. EXPERIMENTAL RESULTS AND DISCUSSION

The charges were conditioned at approximately 21^{o} C for several days prior to firing. Approximately 15 minutes elapsed between the time each of the charges was removed from the conditioning facility and fired. The charges were positioned with a nominal standoff from the spindle face of [illegible] mm, and initiated with M82 primers. After loading, there was an axial distance of approximately [illegible]0 mm between the front of the charge and the base of the projectile.

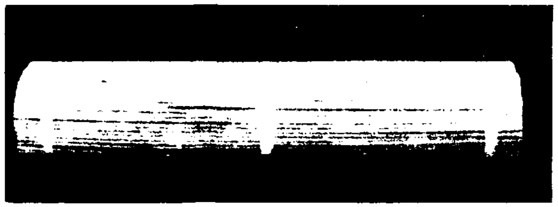


Figure 3. Axially Aligned Charge

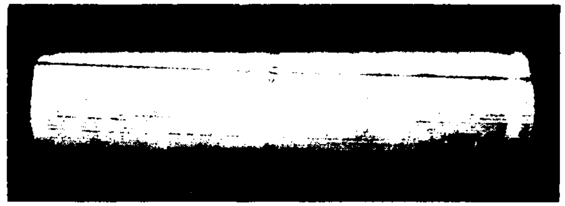


Figure 4. 1/3-Maximum-Twist Charge

Figure 5. 2/3-Maximum-Twist Charge

Figure 6. Maximum-Twist Charge

A. Axially Aligned Charge

The spindle and projectile base pressures and the force measured at the base of the projectile for the charge with the sticks axially aligned are recorded in Figure 7. The times are referenced to the instant at which the firing signal was applied to the primer. Considering the area of the sensing piston of the force gage, the relative scales of the pressure and force plots are such that if only gas pressure were acting on the gages, the curves for the forward pressure and force would approximately overlay one another, thus providing a quick assessment of the amount of solid-phase loading on the base of the projectile. The venting of the primer into the rear ullage behind the charge is clearly seen on the spindle pressure trace. The spindle pressure remained at a very low level during the ignition delay and its behavior remained unremarkable until the chamber fractured at approximately 8.1 MPa. For most of its record, the forward pressure remained nearly coincident with the spindle pressure, reflecting the apparent ease with which gases permeate the stick bed. The maximum difference between the two records is only on the order of 2 MPa over the length of time the data were recorded. The force gage indicated that there was some impact of the propellant on the base of the projectile, as shown in the broad spike on the force gage record. That the pressure as recorded by the force gage is lower than that measured by the pressure gage is difficult to explain; perhaps the piston hung up in its travel, since this was the first firing after the projectile baseplate was assembled and the piston had not been previously exposed to pressures of this magnitude.

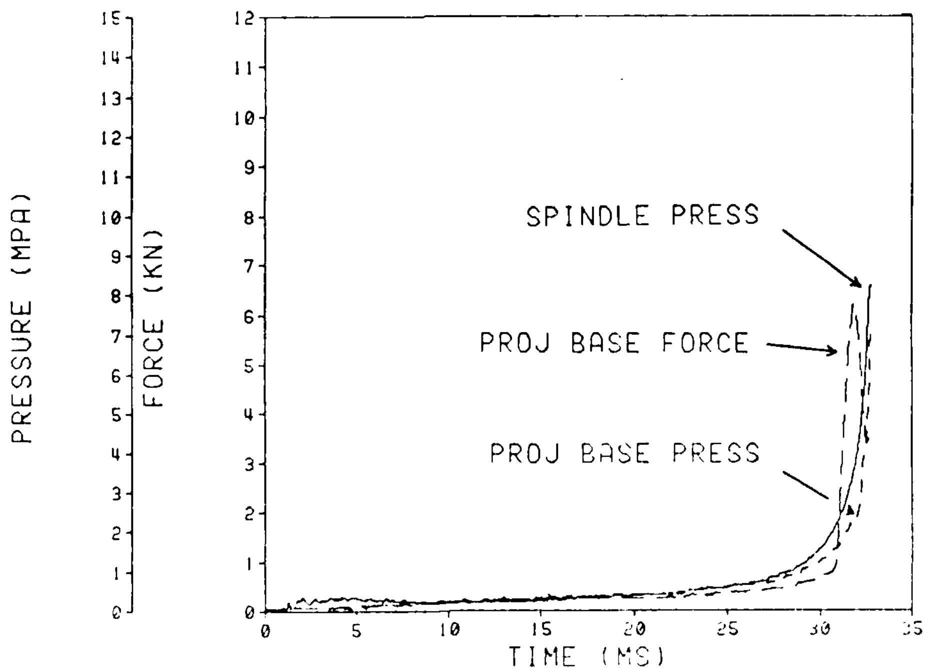


Figure 7. Pressures and Force, Axially Aligned Charge

The high-speed films recorded the path of flamespreading in the chamber during the event. The primer was seen to vent into the rear ullage in a cone-shaped plume at 1.2 ms after application of the firing voltage. The igniter began to burn and the combustion in the rear ullage became more intense, and by 1.9 ms there was some streaming of flame along the top of the charge, this streaming expanding in extent until the rear upper quadrant of the charge was covered at 2.4 ms. This streaming at the top of the charge then decreased in extent and intensity until about 3.1 ms, at which time it began to increase to most of the length of the top of the charge while, the luminosity in the rear ullage became very bright by 5.3 ms. After this time, the luminosity in the rear ullage remained intense, but the extent and luminosity of the streaming decreased until 17.1 ms. The intense luminosity in the rear ullage continued, and at 29.7 ms there was a bright stream of gas along the top of the charge. At 31.1 ms, some luminosity was seen at the front of the charge, and by 32.6 ms there was some brightness along nearly the entire length of the charge when the chamber fractured. At no point was a well-defined flamefront seen to traverse the charge. While it was difficult to pick out the point at which motion of the charge toward the front of the chamber began, the velocity of the bundle as it approached the projectile was on the order of 1 m/s.

The static X-ray taken before the shot clearly showed the stick bundle resting in the chamber, the basepad consisting of the black powder spot and surrounding CBI, the axial ullage of approximately 25 mm between the spindle face and the basepad, and the axial ullage of approximately 50 mm between the front of the stick propellant bundle and the projectile base. No circumferential ullage was visible. The dynamic radiograph, recorded at a spindle pressure of approximately 7 MPa, showed that the stick bundle had moved forward to impact the projectile base. A small extent of circumferential ullage existed at the top of the rear of the charge, in the region of strong gas flow seen in the high-speed films. Not all of the sticks moved forward equally; there were some sticks protruding from the rear of the bundle. Though the charge moved forward to rest against the projectile base, no sticks were seen to fill in the region around the boattail ramp. There was no obvious fracture of propellant in the vicinity of the projectile base, though the radiograph in this region was of poor quality. There was no evidence of any remaining basepad in the dynamic X-ray.

B. <u>One-Third-Maximum-Twist Charge</u>

The spindle and projectile base pressures and the force measured at the base of the projectile are displayed in Figure 8. Again, the spindle pressure was well behaved until the chamber failed at nearly 12 MPa. The ignition delay was shortened considerably in this shot in comparison to that observed in the charge with the axially aligned sticks. The forward chamber pressure did not remain coincident with the spindle pressure as in the previous shot, reflecting the pressure gradient that was established across the twisted stick bundle. The pressure difference at chamber failure was on the order of 9 MPa. There was some impact on the base of the projectile as again evidenced by the broad spike seen on the force gage.

In the high-speed films, the venting of the primer was manifested by an asymmetric cone at 1.2 ms. At 1.4 ms, there was no luminosity in the rear ullage, and only at about 1.8 ms did a slight glow appear in the top half of the rear ullage. By 2.2 ms, the ullage was filled with moderate intensity

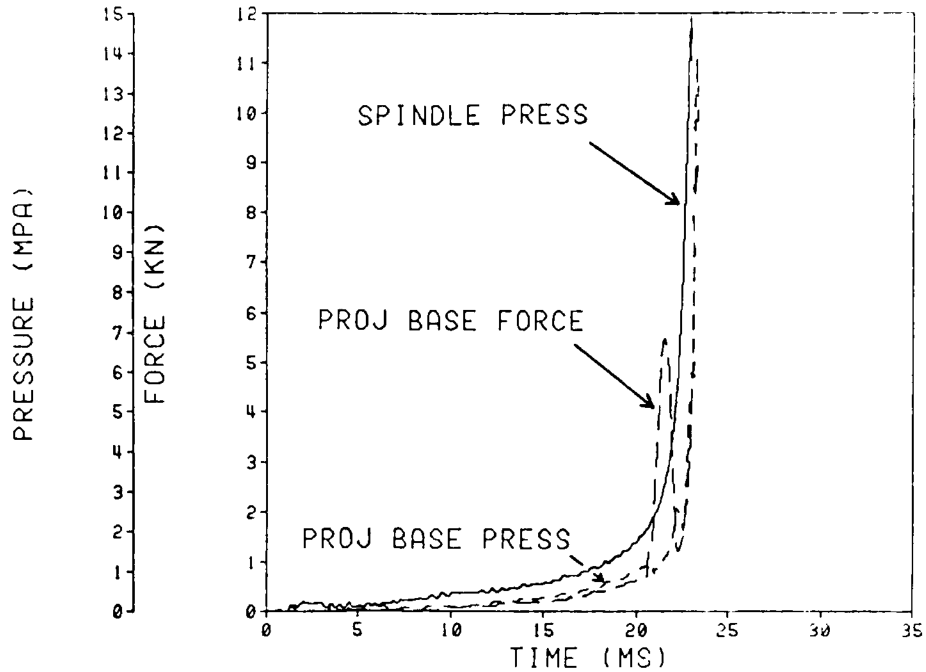


Figure 8. Pressures and Force, 1/3-Maximum-Twist Charge

luminosity, with a tongue of flame streaming along the middle of the charge. This tongue of flame grew longer, then diminished in intensity and extent until it disappeared at 3.8 ms. The luminosity in the rear ullage decreased until there were only hot spots at the top and bottom at 4.5 ms. At 5.3 ms, the luminosity in the rear ullage began to increase, continuing to intensify and feed a dim tongue of flame that extended the length of the charge at its center at 7.9 ms. By 9.2 ms, the luminosity in the rear ullage had become quite intense, and several wavering sheets of flame extended from the rear, these tongues growing in luminosity and extent until they covered nearly the length of the charge at 17.0 ms. At this time, there was still no luminosity at the front of the charge. These bright sheets of flame from the rear continued to waver along the length of the charge, approaching the front of the chamber at 22.9 ms but resulting in no stagnation at the projectile base. By 23.8 ms when the chamber failed, the entire chamber was engulfed in bright luminosity, but no well-defined flamefront through the charge was noted. The maximum velocity noted for the charge was on the order of 2 m/s.

The static X-ray for the 1/3-maximum-twist charge showed all the loading features as described for the axially aligned charge. The twist of the stick was not evident from the X-ray, as the charge appeared as only a solid mass. The dynamic radiograph was recorded at a spindle pressure of approximately MPa. As with the previous shot, the stick bundle moved forward to the projectile base, but no sticks moved forward to fill in the region around the boattail. There was no evidence of any basepad materials in the rear ullage. There was some circumferential ullage along the bottom of the charge near the forward end of the chamber where the twist of the sticks was obvious. No evidence of breakage of the propellant sticks in the region of the projectile base was found from the dynamic X-ray.

C. Two-Thirds-Maximum-Twist Charge

The spindle and projecti'e base pressures and the force measured at the base of the projectile for the 2/3-maximum-twist charge are displayed in Figure 9. The ignition delay for this charge was shorter yet than that recorded with the 1/3-maximum-twist charge. Both pressure curves were well behaved, with an obvious pressure gradient established between the two recording locations. The maximum difference reached between the two pressures was on the order of 7 MPa, noted before chamber failure. The remarkable result from this firing is seen by examination of the force record: the force curve remained coincident with the forward pressure curve for the duration of the event, indicating either no impact of the stick bundle on the base of the projectile or one so gentle that it produced no significant response on the gage.

The ambient lighting at the time of firing was such that the best view on the high-speed films of the solid-phase dynamics was obtained on this shot. The M82 primer was seen to vent into the rear ullage at 1.4 ms. The ullage was filled with smoke at 1.6 ms, and at 1.8 ms the basepad began to burn, feeding a small tongue of flame along the rear of the charge at 2.1 ms. At 2.6 ms, there was a stream of flame running diagonally along a portion of the length of the charge in the same direction as the twist of the sticks. This stream began to dim at 2.8 ms, and all the luminosity in the chamber decreased so that at 4.5 ms, there was virtually no luminosity even in the rear ullage.

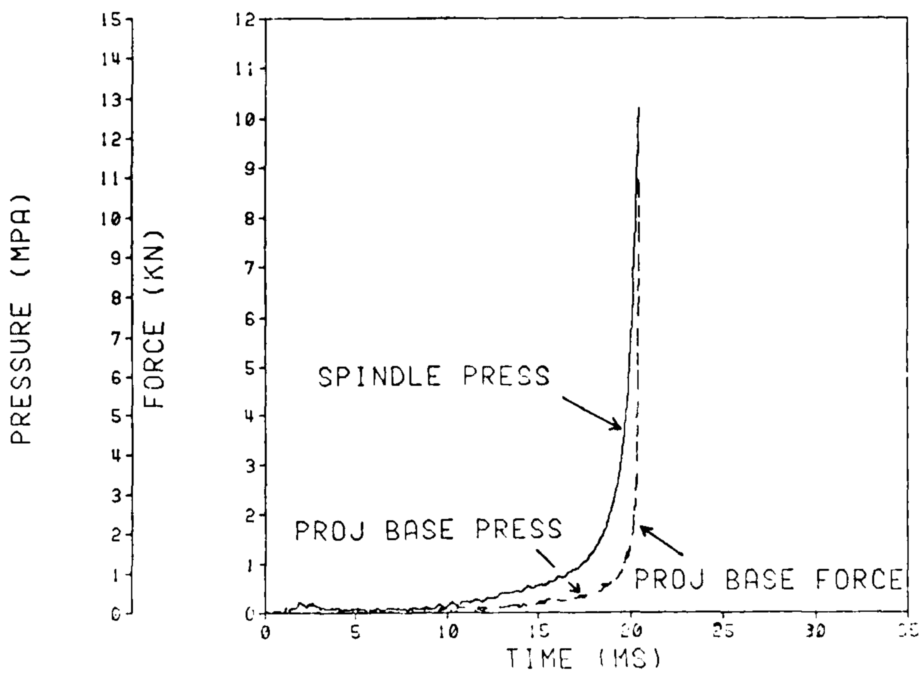


Figure 9. Pressures and Force, 2/3-Maximum-Twist Charge

At 5.0 ms, there was once again flame in the rear ullage, increasing in intensity until 7.1 ms, when a stream of burning gases extended from the rear along the middle of the charge. By 7.8 ms, there was significantly more streaming, showing some preferential flow along the twist of the sticks. This streaming continued, with smoke becoming visible in the ullage between the front of the stick bundle and projectile at 10.1 ms. With some streaming of the flame continuing with a slight preference along the twist of the sticks, the forward ullage was filled with smoke by 13.5 ms. At 17.3 ms, there were only small tongues of flame extending from the rear ullage, but they became longer by 18.7 ms when the streaming obviously followed the twist of the sticks. At 19.6 ms, half the bed was engulfed in wavering flames, with only smoke at the front of the charge. At 20.3 ms, nearly all the bed was covered by flame, with some spots apparently hotter than others. By the time the chamber fractured at 20.8 ms, only a small dark spot remained at the forward end of the chamber. Again for this shot, no well-defined flamefront developed. The maximum velocity reached by the stick bundle was on the order of 10 m/s, but it was impossible to measure the velocity just prior to impact due to poor lighting in the region.

The static X-ray for the 2/3-maximum-twist charge again showed all the loading features as described for the axially aligned charge. That there was some twist to the stick bundle was apparent in the static X-ray, though it was impossible to trace individual sticks through the charge. The image showed up in some places as crisscrossing lines since the radiograph is a planar projection of the entire thickness of the charge. The dynamic X-ray, taken at a spindle pressure of approximately 7 MPa, showed that the stick bundle had also in this instance moved forward to rest against the base of the projectile. There was some slight shadows of basepad materials in the rear ullage, but it was impossible to distinguish any individual basepad components. There was some opening up of space between the sticks near the forward end of the charge and in a region near the top rear of the charge, and the twist of the sticks was most obvious at these locations. No evidence of fracture of the sticks anywhere in the charge was apparent from the dynamic X-ray.

D. Maximum-Twist Charge

The spindle and projectile base pressures and the force measured at the base of the projectile for the maximum-twist charge are displayed in Figure 10. All of the curves appear quite similar to those obtained with the 2/3-maximum-twist charge. The ignition delay was again shortened in comparison with that of the axially aligned charge, but there was no noticeable difference between the delay with this charge and the previous one. Again, the pressure gradient established between the ends of the stick bundle is apparent, reaching a maximum on the order of 7 MPa at chamber failure. There was no strong impact of the propellant bed upon the projectile base as read from the force gage, although the higher force gage record perhaps indicated some small solid-phase force on the projectile base.

On the high-speed films for this shot, the primer was seen to vent onto the of the charge at 1.4 ms, and by 1.6 ms, the ullage was filled with a bright luminosity. The basepad continued to burn, with a short extent of flame along the top of the charge at 2.1 ms. Progressively, this tongue of flame died out, and luminosity in the rear ullage was reduced considerably by 3.3 ms. The luminosity at the rear continued at a low intensity, with some

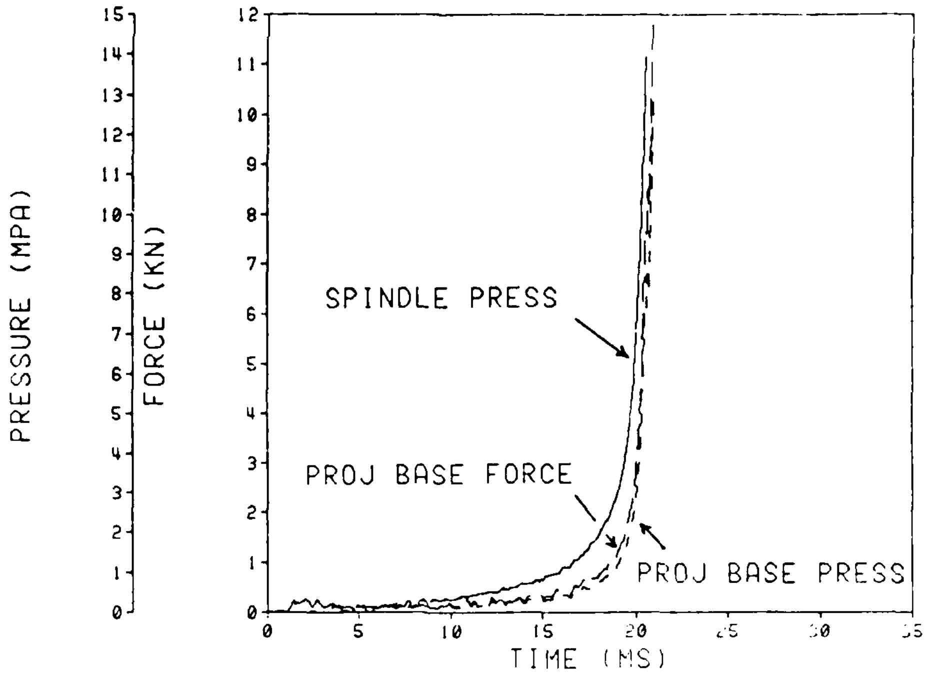


Figure 10. Pressures and Force, Maximum-Twist Charge

turbulence noted in the ullage at around 5.6 ms. At 6.1 ms, the luminosity in the rear ullage began to increase, and by 6.8 ms, there were two thin streamers of flame at the top of the charge extending nearly a third the length of the chamber. By 7.7 ms, this had evolved into a single sheet of flame covering the top half of the charge and extending nearly half its length. This stream of flame continued to develop along the top of the charge until 9.7 ms, when it began to break up and become dimmer. At 12.1 ms, the luminosity in the rear ullage was still great, but there were only a couple of small wisps of flame extending half the length of the charge. These wisps continued to develop, and from about 14.5 ms until 19.1 ms, a well defined stream of flame developed along the diagonal from the top rear to the bottom front portion of the charge, very obviously following the twist of the stick bundle. Finally, a pulse of flame, beginning near the middle of the charge, traversed to the front of the charge just before the chamber failed. At no time during the event was there a well-defined flamefront. While it was more difficult to obtain velocities of the propellant on this shot, the maximum velocity appeared to be slightly greater than that obtained on the 2/3-maximum-twist shot.

The static X-ray for the maximum-twist charge again showed all the loading features as described for the axially aligned charge. The dynamic X-ray was recorded at a spindle pressure of approximately 7 MPa and showed that this stick bundle too moved forward to impact the base of the projectile. No trace of any igniter materials remained in the rear ullage. There was some space visible between sticks at the top rear and bottom forward portions of the charge and once again, the twist of the sticks was most obvious in these locations. No sticks moved forward to fill in the area around the projectile boattail ramp. There was no evidence of breakup of the propellant grains.

IV. CONCLUSIONS

While it is not wise to draw sweeping conclusions from such a limited number of shots, several observations can be made from the body of data obtained in the simulator with these stick charges of progressively increasing obliquity to the axis of the chamber.

First, we note an underscoring of a lesson learned from tests with combustible-case stick charges: while the flow of gases within a stick propellant bundled is relatively unimpeded due to the natural flow channels, gases may have difficulty entering the stick bundle due to the discontinuity in porosity at the interface. The high-speed films demonstrated this fact in that the igniter gases remained in the rear ullage for a substantial period of time before entering the stick bed.

The ignition delays decreased as the obliquity of the stick loading increased. This is almost certainly a consequence of the igniter gases, being produced in a constrained volume, being unable to easily find relief through entry into the stick bed, thus pressurizing the rear ullage to a greater extent for the more twisted charges. Such higher pressurization would lead to earlier sustained combustion of the affected portions of the charge, reducing the ignition delay.

Also as a consequence of the relative difficulty of flow of gases through the stick bed, we noted a tendency for increased pressure differentials across the bed for even a small degree of twist. However, the levels remained low enough - less than 10 MPa during the flamespreading period - that they are probably not ballistically significant.

As with all of our previous work with stick charges in the simulator, we again failed to observe a well-defined progression of a flamefront though the charge as has been seen with granular charges. Rather, the gases seem to stream through or around the stick bundle at favorable locations, bringing the propellants to ignition at seemingly random locations but with rapid combustion nearly uniformly along the length of the charge.

Finally we note that all the charges moved forward to impact the base of the projectile, to varying degrees of severity not clearly dependent on the intuitive resistance to gas flow. Perhaps contrary to expectation, the two charges with the greatest solid-phase loading on the projectile were those with the least amount of obliquity, those with the expected least resistance. It has been suggested[8] that this lack of a strong impact of the more twisted bundles on the base of the projectile might be a result of friction between the charge bundle and the chamber wall. As the igniter and early combustion gases follow the flow channels in a the twisted-stick bundle, there will be a component of gas flow normal to the chamber axis, resulting in forces tending

[8] Albert W. Horst, private communication, November 1987.

to expand the bundle against the chamber wall. It would be expected that the forces would increase with greater obliquity, yielding higher frictional forces between the charge and chamber wall and resulting in less of a tendency for the charge to be propelled against the projectile base. Alternatively, it has been pointed out[9] that this finding might be a result of the fabrication method of the stick bundles. In the progression of layers of sticks from the interior to the exterior of the charge, the sticks became increasing more twisted about the bundle so that the outer sticks occupied less axial extent than the inner sticks. A possible result of this geometry is that the end of stick bundle was not completely flat, with the sticks at the center region of the charge protruding slightly from the end of the bundle. While not noticeable, this slight protrusion may have impacted the base of the projectile at the center, away from the force gage locations, thereby cushioning the impact of the remainder of the charge on the gages. While all of the charges impacted the projectile base, there was no evidence from the radiographs of any stick breakage.

This study has provided further insight into those events transpiring during the flamespreading process with stick propellant charges and furnished the first detailed view of the effects on this process of oblique loading of the stick propellants. The testing in the simulator would seem to indicate that such a loading configuration, at least to the extent of the twist studied here, would have no real ballistic significance. However, to fully substantiate this statement, full-scale ballistic testing will be required. Additional testing, planned for the future at BRL in a flow fixture that pushes inert gases through beds of propellant simulants and permits measurements of pressure drops along the bed, will be required to develop the experimental correlations for flows such as those described here for inclusion into multiphase flow models.

ACKNOWLEDGMENTS

The author is grateful to Mr. J. Rutkowski of the ARDEC, Dover, NJ for providing the stick propellants used in this study. The author also wishes to thank Mr. A. Koszoru, Mr. D. Kruczynski, and Mr. O. Doali of the BRL for constructing the test charges and Mr. J. Bowen, Mr. J. Hewitt, Mr. J. Stabile, and Mr. J. Tuerk, also of the BRL, for invaluable assistance in carrying out the firing program.

---

[9]Paul S. Gough, private communication, October 1986.

REFERENCES

1. David L. Kruczynski, "Final Report: Product Improvement Test of 155-mm Propelling Charge M203E2," Combat Systems Test Activity, USA TECOM, Aberdeen Proving Ground, MD, January 1986.

2. Sandor Einstein, Scott Westley, and Robert Garufi, "Development of a Single-Base Stick, 155-mm, Modular Charge," Proceedings of 1986 JANNAF Propulsion Meeting, CPIA Publication 455, Vol. IV, pp. 131-136, August 1986.

3. Aaron Grabowsky, Philip Hui, and Donald Chui, "Unicharge for Integrated Smart Artillery Synthesis," Proceedings of 1985 JANNAF Propulsion Meeting, CPIA Publication 425, Vol. III, pp. 453-465, April 1985.

4. Thomas C. Minor, "Experimental Studies of Multidimensional, Two-Phase Flow Processes in Interior Ballistics," ARBRL-MR-03248, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, April 1983.

5. Thomas C. Minor and Albert W. Horst, "Ignition Phenomena in Developmental, Combustible-Cased, 155-mm, M203E2 Propelling Charges," ARBRL-TR-02568, Ballistic Research Laboratory, USA AMCCOM, Aberdeen Proving Ground, MD, July 1984.

6. Thomas C. Minor and Albert W. Horst, "Theoretical and Experimental Investigation of Flamespreading Processes in Combustible-Cased, Stick Propellant Charges," BRL-TR-2710, Ballistic Research Laboratory, USA LABCOM, Aberdeen Proving Ground, MD, February 1986.

7. F.W. Robbins and A.W. Horst, "High-Progressivity/Density (HPD) Propelling Charge Concepts: Progress of Programmed-Splitting Stick Propellant," BRL-MR-3547, Ballistic Research Laboratory, USA LABCOM, Aberdeen Proving Ground, MD, September 1986.

8. Albert W. Horst, private communication, November 1987.

9. Paul S. Gough, private communication, October 1986.

DISTRIBUTION LIST

No. of Copies	Organization
12	Administrator Defense Technical Info Center ATTN: DTIC-FDAC Cameron Station, Bldg 5 Alexandria, VA 22304-6145
1	Commander USA Concepts Analysis Agency ATTN: D. Hardison 8120 Woodmont Avenue Bethesda, MD 20014-2797
1	HQDA/DAMA-ZA Washington, DC 20310-2500
1	HQDA, DAMA-CSM, Washington, DC 20310-2500
1	HQDA/SARDA Washington, DC 20310-2500
1	C.I.A. OIR/DB/Standard GE47 HQ Washington, D.C. 20505
1	Commander US Army War College ATTN: Library-FF229 Carlisle Barracks, PA 17013
1	US Army Ballistic Missile Defense Systems Command Advanced Technology Center P. O. Box 1500 Huntsville, AL 35807-3801
1	Chairman DOD Explosives Safety Board Room 856-C Hoffman Bldg. 1 2461 Eisenhower Avenue Alexandria, VA 22331-9999
1	Commander US Army Materiel Command ATTN: AMCPM-GCM-WF 5001 Eisenhower Avenue Alexandria, VA 22333-5001
1	Commander US Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-5001
1	Commander US Army Materiel Command ATTN: AMCDE-DW 5001 Eisenhower Avenue Alexandria, VA 22333-5001

No. of Copies	Organization
5	Project Manager Cannon Artillery Weapons System, ARDC, AMCCOM ATTN: AMCPM-CW, AMCPM-CWW AMCPM-CWS M. Fisette AMCPM-CWA H. Hassmann AMCPM-CWA-S R. DeKleine Dover, NJ 07801-5001
2	Project Manager Munitions Production Base Modernization and Expansion ATTN: AMCPM-PBM, A. Siklosi AMCPM-PBM-E, L. Laibson Dover, NJ 07801-5001
3	Project Manager Tank Main Armament System ATTN: AMCPM-TMA, K. Russell AMCPM-TMA-105 AMCPM-TMA-120 Dover, NJ 07801-5001
1	Commander US Army Watervliet Arsenal ATTN: SARWV-RD, R. Thierry Watervliet, NY 12189-5001
1	Commander U.S. Army ARDEC ATTN: SMCAR-MSI Dover, NJ 07801-5001
1	Commander U.S. Army ARDEC ATTN: SMCAR-TDC Dover, NJ 07801-5001
4	Commander US Army Armament Munitions and Chemical Command ATTN: AMSMC-IMP-L Rock Island, IL 61299-7300
1	HQDA DAMA-ART-M Washington, DC 20310-2500
1	Commander US Army AMCCOM ARDEC CCAC ATTN: SMCAR-CCB-TL Benet Weapons Laboratory Watervliet, NY 12189-4050

DISTRIBUTION LIST

No. of Copies	Organization
3	Commander US Army ARDEC ATTN: SMCAR-MSI SMCAR-TDC SMCAR-LC LTC N. Barron Dover, NJ 07801-5001
7	Commander US Army ARDEC ATTN: SMCAR-LCA A. Beardell D. Downs S. Einstein S. Westley S. Bernstein C. Roller J. Rutkowski Dover, NJ 07801-5001
3	Commander US Army ARDEC ATTN: SMCAR-LCB-I D. Spring SMCAR-LCE SMCAR-LCM-E S. Kaplowitz Dover, NJ 07801-5001
4	Commander US Army ARDEC ATTN: SMCAR-LCS SMCAR-LCU-CT E. Barrieres R. Davitt SMCAR-LCU-CV C. Mandala Dover, NJ 07801-5001
3	Commander US Army ARDEC ATTN: SMCAR-LCW-A M. Salsbury SMCAR-SCA L. Stiefel B. Brodman Dover, NJ 07801-5001
1	Commander US Army Aviation Systems Command ATTN: AMSAV-ES 4300 Goodfellow Blvd. St. Louis, MO 63120-1798
1	Director US Army Aviation Research and Technology Activity Ames Research Center Moffett Field, CA 94035-1099
1	Commander US Army Communications - Electronics Command ATTN: AMSEL-ED Fort Monmouth, NJ 07703-5301
1	Commander CECOM R&D Technical Library ATTN: AMSEL-M-L (Report Section) B.2700 Fort Monmouth, NJ 07703-5000
1	Commander US Army Harry Diamond Lab. ATTN: DELHD-TA-L 2800 Powder Mill Road Adelphi, MD 20783-1145
1	Commander US Army Missile Command ATTN: AMSMI-RX M.W. Thauer Redstone Arsenal, AL 35898-5249
1	Commander US Army Missile and Space Intelligence Center ATTN: AIAMS-YDL Redstone Arsenal, AL 35898-5500
1	Commander US Army Missile Command Research, Development, and Engineering Center ATTN: AMSMI-RD Redstone Arsenal, AL 35898-5245
1	Commandant US Army Aviation School ATTN: Aviation Agency Fort Rucker, AL 36360
1	Commander US Army Tank Automotive Command ATTN: AMSTA-TSL Warren, MI 48397-5000
1	Commander US Army Tank Automotive Command ATTN: AMSTA-CG Warren, MI 48397-5000

DISTRIBUTION LIST

No. of Copies	Organization
1	Project Manager Improved TOW Vehicle ATTN: AMCPM-ITV US Army Tank Automotive Command Warren, MI 48397-5000
2	Program Manager M1 Abrams Tank System ATTN: AMCPM-GMC-SA, T. Dean Warren, MI 48092-2498
1	Project Manager Fighting Vehicle Systems ATTN: AMCPM-FVS Warren, MI 48092-2498
1	President US Army Armor & Engineer Board ATTN: ATZK-AD-S Fort Knox, KY 40121-5200
1	Project Manager M-60 Tank Development ATTN: AMCPM-M60TD Warren, MI 48092-2498
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATOR-TSL White Sands Missile Range, NM 88002
1	Commander US Army Training & Doctrine Command ATTN: ATCD-MA/ MAJ Williams Fort Monroe, VA 23651
2	Commander US Army Materials and Mechanics Research Center ATTN: AMXMR-ATL Tech Library Watertown, MA 02172
1	Commander US Army Research Office ATTN: Tech Library P. O. Box 12211 Research Triangle Park, NC 27709-2211
1	Commander US Army Belvoir Research and Development Center ATTN: STRBE-WC Fort Belvoir, VA 22060-5606
1	Commander US Army Logistics Mgmt Ctr Defense Logistics Studies Fort Lee, VA 23801
1	Commandant US Army Infantry School ATTN: ATSH-CD-CS-OR Fort Benning, GA 31905-5400
1	Commandant US Army Command and General Staff College Fort Leavenworth, KS 66027
1	Commandant US Army Special Warfare School ATTN: Rev & Tng Lit Div Fort Bragg, NC 28307
3	Commander Radford Army Ammunition Plant ATTN: SMCRA-QA/HI LIB Radford, VA 24141-0298
1	Commander US Army Foreign Science & Technology Center ATTN: AMXST-MC-3 220 Seventh Street, NE Charlottesville, VA 22901-5396
2	Commandant US Army Field Artillery Center & School ATTN: ATSF-CO-MW, B. Willis Ft. Sill, OK 73503-5600
1	Commander US Army Development and Employment Agency ATTN: MODE-ORO Fort Lewis, WA 98433-5099
1	Office of Naval Research ATTN: Code 473, R. S. Miller 800 N. Quincy Street Arlington, VA 22217-9999
3	Commandant US Army Armor School ATTN: ATZK-CD-MS M. Falkovitch Armor Agency Fort Knox, KY 40121-5215

DISTRIBUTION LIST

No. of Copies	Organization
2	Commander Naval Sea Systems Command ATTN: SEA 62R SEA 64 Washington, DC 20362-5101
1	Commander Naval Air Systems Command ATTN: AIR-954-Tech Lib Washington, DC 20360
1	Assistant Secretary of the Navy (R, E, and S) ATTN: R. Reichenbach Room 5E787 Pentagon Bldg. Washington, DC 20350
1	Naval Research Lab Tech Library Washington, DC 20375
5	Commander Naval Surface Weapons Center ATTN: Code G33, J. L. East W. Burrell J. Johndrow Code G23, D. McClure Code DX-21 Tech Lib Dahlgren, VA 22448-5000
2	Comander US Naval Surface Weapons Center ATTN: J. P. Consaga C. Gotzmer Indian Head, MD 20640-5000
4	Commander Naval Surface Weapons Center ATTN: S. Jacobs/Code 240 Code 730 K. Kim/Code R-13 R. Bernecker Silver Spring, MD 20903-5000
2	Commanding Officer Naval Underwater Systems Center Energy Conversion Dept. ATTN: CODE 5B331, R. S. Lazar Tech Lib Newport, RI 02840
4	Commander Naval Weapons Center ATTN: Code 388, R. L. Derr C. F. Price T. Boggs Info. Sci. Div. China Lake, CA 93555-6001
2	Superintendent Naval Postgraduate School Dept. of Mech. Engineering Monterey, CA 93943-5100
1	Program Manager AFOSR Directorate of Aerospace Sciences ATTN: L. H. Caveny Bolling AFB, DC 20332-0001
5	Commander Naval Ordnance Station ATTN: P. L. Stang L Torreyson T. C. Smith D. Brooks Tech Library Indian Head, MD 20640-5000
1	AFSC/SDOA Andrews AFB, MD 20334
3	AFRPL/DY, Stop 24 ATTN: J. Levine/DYCR R. Corley/DYC D. Williams/DYCC Edwards AFB, CA 93523-5000
1	AFRPL/TSTL (Tech Library) Stop 24 Edwards AFB, CA 93523-5000
1	AFATL/DLYV Eglin AFB, FL 32542-5000
1	AFATL/DLXP Eglin AFB, FL 32542-5000
1	AFATL/DLJE Eglin AFB, FL 32542-5000
1	AFATL/DOIL ATTN: (Tech Info Center) Eglin AFB, FL 32542-5438
1	NASA/Lyndon B. Johnson Space Center ATTN: NHS-22, Library Section Houston, TX 77054
1	AFELM, The Rand Corporation ATTN: Library D 1700 Main Street Santa Monica CA 90401-3297

DISTRIBUTION LIST

No. of Copies	Organization
1	General Applied Sciences Lab ATTN: J. Erdos Merrick & Stewart Avenues Westbury Long Isld, NY 11590
2	AAI Corporation ATTN: J. Hebert J. Frankle D. Cleveland P. O. Box 6767 Baltimore, MD 21204
1	Aerojet Ordnance Company ATTN: D. Thatcher 2521 Michelle Drive Tustin, CA 92680-7014
1	Aerojet Solid Propulsion Co. ATTN: P. Micheli Sacramento, CA 95813
1	Atlantic Research Corporation ATTN: M. K. King 5390 Cheorokee Avenue Alexandria, VA 22312-2302
1	AVCO Everett Rsch Lab ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149-5936
2	Calspan Corporation ATTN: C. Morphy P. O. Box 400 Buffalo, NY 14225-0400
1	General Electric Company Armament Systems Dept. ATTN: M. J. Bulman, Room 1311 128 Lakeside Avenue Burlington, VT 05401-4985
1	IITRI ATTN: M. J. Klein 10 W. 35th Street Chicago, IL 60616-3799
1	Hercules Inc. Allegheny Ballistics Laboratory ATTN: R. B. Miller P. O. Box 210 Cumberland, MD 21501-0210
1	Hercules, Inc. Bacchus Works ATTN: K. P. McCarty P. O. Box 98 Magna, UT 84044-0098

No. of Copies	Organization
1	Hercules, Inc. Radford Army Ammunition Plant ATTN: J. Pierce Radford, VA 24141-0299
1	Honeywell, Inc. - MN64 2200 Defense Systems Division ATTN: C. Hargreaves 6110 Blue Circle Drive Minnetonka MN 55436
1	Lawrence Livermore National Laboratory ATTN: L-355, A. Buckingham M. Finger P. O. Box 808 Livermore, CA 94550-0622
1	Lawrence Livermore National Laboratory ATTN: L-324/M. Constantino P. O. Box 808 Livermore, CA 94550-0622
1	Olin Corporation Badger Army Ammunition Plant ATTN: R. J. Thiede Baraboo, WI 53913
1	Olin Corporation Smokeless Powder Operations ATTN: D. C. Mann P.O. Box 222 St. Marks, FL 32355-0222
1	Paul Gough Associates, Inc. ATTN: P. S. Gough P. O. Box 1614, 1048 South St. Portsmouth, NH 03801-1614
1	Physics International Company ATTN: Library H. Wayne Wampler 2700 Merced Street San Leandro, CA 94577-5602
1	Princeton Combustion Research Lab., Inc. ATTN: M. Summerfield 475 US Highway One Monmouth Junction, NJ 08852-9650
2	Rockwell International Rocketdyne Division ATTN: BA08 J. E. Flanagan J. Gray 6633 Canoga Avenue Canoga Park, CA 91303-2703

DISTRIBUTION LIST

No. of Copies	Organization
1	Science Applications, Inc. ATTN: R. B. Edelman 23146 Cumorah Crest Drive Woodland Hills, CA 91364-3710
3	Thiokol Corporation Huntsville Division ATTN: D. Flanigan R. Glick Tech Library Huntsville, AL 35807
2	Thiokol Corporation Elkton Division ATTN: R. Biddle Tech Lib. P. O. Box 241 Elkton, MD 21921-0241
2	United Technologies Chemical Systems Division ATTN: R. Brown Tech Library P. O. Box 358 Sunnyvale, CA 94086-9998
1	Veritay Technology, Inc. ATTN: E. Fisher 4845 Millersport Hwy. P. O. Box 305 East Amherst, NY 14051-0305
1	Universal Propulsion Company ATTN: H. J. McSpadden Black Canyon Stage 1 Box 1140 Phoenix, AZ 85029
1	Battelle Memorial Institute ATTN: Tech Library 505 King Avenue Columbus, OH 43201-2693
1	Brigham Young University Dept. of Chemical Engineering ATTN: M. Beckstead Provo, UT 84601
1	California Institute of Tech 204 Karman Lab Main Stop 301-46 ATTN: F. E. C. Culick 1201 E. California Street Pasadena, CA 91109
1	California Institute of Tech Jet Propulsion Laboratory ATTN: L. D. Strand 4800 Oak Grove Drive Pasadena, CA 91109-8099

No. of Copies	Organization
1	University of Illinois Dept of Mech/Indust Engr ATTN: H. Krier 144 MEB; 1206 N. Green St. Urbana, IL 61801-2978
1	University of Massachusetts Dept. of Mech. Engineering ATTN: K. Jakus Amherst, MA 01002-0014
1	University of Minnesota Dept. of Mech. Engineering ATTN: E. Fletcher Minneapolis, MN 55414-3368
1	Case Western Reserve University Division of Aerospace Sciences ATTN: J. Tien Cleveland, OH 44135
3	Georgia Institute of Tech School of Aerospace Eng. ATTN: B. T. Zinn E. Price W. C. Strahle Atlanta, GA 30332
1	Institute of Gas Technology ATTN: D. Gidaspow 3424 S. State Street Chicago, IL 60616-3896
1	Johns Hopkins University Applied Physics Laboratory Chemical Propulsion Information Agency ATTN: T. Christian Johns Hopkins Road Laurel, MD 20707-0690
1	Massachusetts Institute of Technology Dept of Mechanical Engineering ATTN: T. Toong 77 Massachetts Avenue Cambridge, MA 02139-4307
1	G. M. Faeth Pennsylvania State University Applied Research Laboratory University Park, PA 16802-7501
1	Pennsylvania State University Dept. of Mech. Engineering ATTN: K. Kuo University Park, PA 16802-7501

DISTRIBUTION LIST

No. of Copies	Organization
1	Purdue University School of Mechanical Engineering ATTN: J. R. Osborn TSPC Chaffee Hall West Lafayette, IN 47907-1199
1	SRI International Propulsion Sciences Division ATTN: Tech Library 333 Ravenswood Avenue Menlo Park, CA 94025-3493
1	Rensselaer Polytechnic Inst. Department of Mathematics Troy, NY 12181
2	Director Los Alamos Scientific Lab ATTN: T3, D. Butler M. Division, B. Craig P. O. Box 1663 Los Alamos, NM 87544
1	Stevens Institute of Technology Davidson Laboratory ATTN: R. McAlevy, III Castle Point Station Hoboken, NJ 07030-5907
1	Rutgers University Dept. of Mechanical and Aerospace Engineering ATTN: S. Temkin University Heights Campus New Brunswick, NJ 08903
1	University of Southern California Mechanical Engineering Dept. ATTN: 0HE200, M. Gerstein Los Angeles, CA 90089-5199
2	University of Utah Dept. of Chemical Engineering ATTN: A. Baer G. Flandro Salt Lake City, UT 84112-1194
1	Washington State University Dept. of Mech. Engineering ATTN: C. T. Crowe Pullman, WA 99163-5201

Aberdeen Proving Ground

Dir, USAMSAA
ATTN: AMXSY-D
AMXSY-MP, H. Cohen

No. of Copies	Organization
	Cdr, USATECOM ATTN: AMSTE-SI-F AMSTE-CM-F, L. Nealley
	Cdr, CSTA ATTN: STECS-AS-H, R. Hendricksen
	Cdr, CRDC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-SPS-IL

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. BRL Report Number____________________Date of Report__________

2. Date Report Received______________________________

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.)__________

4. How specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.)__________

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided or efficiencies achieved, etc? If so, please elaborate.__________

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.)

CURRENT ADDRESS

Name

Organization

Address

City, State, Zip

7. If indicating a Change of Address or Address Correction, please provide the New or Correct Address in Block 6 above and the Old or Incorrect address below.

OLD ADDRESS

Name

Organization

Address

City, State, Zip

(Remove this sheet, fold as indicated, staple or tape closed, and mail.)

FOLD HERE

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO 12062 WASHINGTON, DC
POSTAGE WILL BE PAID BY DEPARTMENT OF THE ARMY

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-9989

FOLD HERE

END
DATED
FILM
8-88
DTIC